UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

**Investigation into Sustainable Light Bulbs**

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# Investigation into Sustainable Light Bulbs

**Sustainable Lighting Options for the New Student Union Building at UBC**


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# ABSTRACT

This report conducts a triple-bottom-line-comparison of three lighting options for the new Student Union Building. This method takes into account the social, environmental, and economic impact of the different available options. The scope of this report is limited to the three leading technologies in this field: incandescent, compact florescent lights (CLF), and light emitting diode (LED). Each option has been evaluated on its complete lifecycle in the following areas: materials and production, usage, and recycling and disposal.

In the area of production, CFL's and incandescent bulbs have the advantage due to streamlined production techniques and thus have a lower input energy per bulb ratio when compared to LEDs. LEDs have a disadvantage in this area because they are a new technology and the production volumes and methods have not been optimized. However, when the raw input materials that go into each bulb are considered, LEDs have a distinct advantage because LEDs contain no toxic chemicals or unsustainable materials. This is in contrast to incandescent and CFL, as they rely on tungsten and mercury, respectively, to emit light. Although all three options have draw backs in this category, LEDs are the only option where significant improvement is possible; as the technology progresses the production process will become more efficient.

When calculating the total energy used for each option, the efficiency, lifetime, and energy per lumen must be taken into account. In order to get an accurate comparison, we examined each option over 60,000 hours of usage. The results indicate that LEDs are the most efficient, followed closely by CFL's, and incandescent being significantly worse. Even though LEDs are more efficient on a per bulb basis, CFLs have a higher lumen per watt ratio, giving them the overall advantage.

Evaluating each option on their methods of disposal finds that CFLs have the most extensive recycling programs in place. Although this in itself is a plus, it can be directly attributed to the presence of mercury contained within the bulb. Incandescent bulbs can be mostly recycled, but the cost is higher than the production costs for a new bulb. The problem with evaluating the disposal and recycling methods for the LED is that even though the LED is almost 100% recyclable, because the technology is new, there are no programs in place to do so. Because of this, one can only speculate that programs will be put in place once the technology is more widely implemented. For these reasons, the best present option is the CFL.

As the LED is the most sustainable long term choice, it is the best option for use in the New SUB on the condition that recycling programs are established in the near future. Otherwise, CFLs provide a good alternative, with a few minor drawbacks.

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# 1.0 INTRODUCTION

The choice of lighting used in the new Student Union Building (SUB) will have a huge impact on the overall sustainability and both the operational and initial costs of the building. In order to achieve UBC's goal of becoming a global leader in campus sustainability (TREK 2010), seemingly small decisions must be properly analyzed and assessed in terms of total impact rather than the traditional bottom line technique. This report conducts a triple-bottom-line-comparison of lighting options for use in the daily operations of the planned SUB. By doing so, the social, environmental and economic impacts will be accounted for over the complete lifetime of three lighting choices: incandescent, compact fluorescent lamps (CFL), and light emitting diode (LED).

## 2.0 MATERIALS AND PRODUCTION

The effect a light bulb has on the environment starts even before the light bulb is made. Minerals and precious metals must be extracted from the earth in order to fabricate each light bulb, and different bulbs require different materials. During production, harmful toxins can be released into the atmosphere, while packaging and shipping a final product increases its carbon footprint.

### 2.1 Incandescent

The incandescent light bulb consists of three major parts: the bulb, the filament and the base as shown in Figure 1. The bulb is simply a shell made of glass. Glass is typically made of pure silica, with trace elements of sodium carbonate, magnesium oxide and aluminum oxide in order to increase strength and reduce production costs (Madehow, 2009). Although these materials are found abundantly throughout the world, they must be considered finite resources.

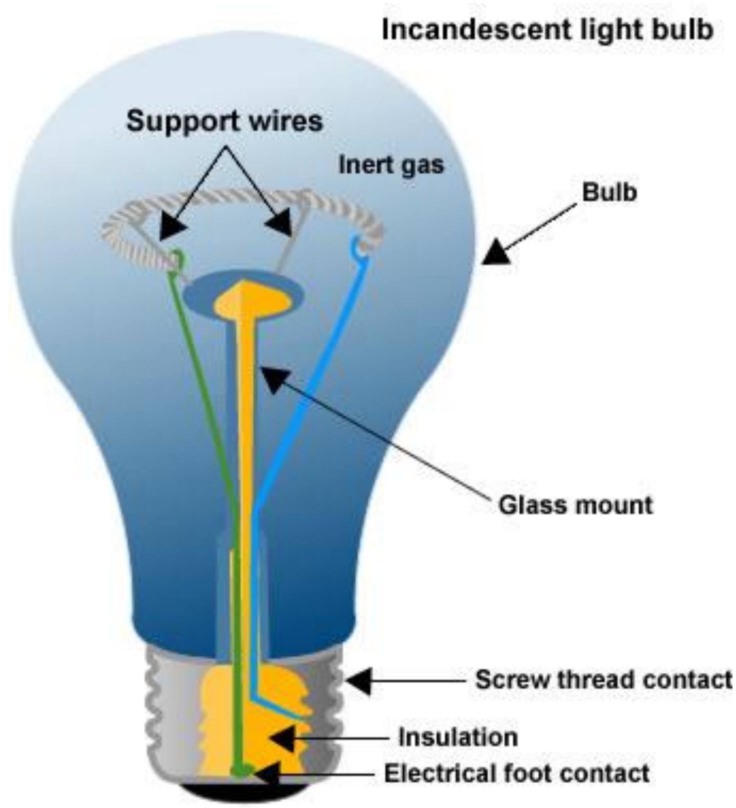


Figure 1: The Incandescent Light Bulb
*Source: http://www.energycrysis.com*

The extracting and refining process of the elements contained in the bulb can be done with minimal environmental impact.

The tungsten filament of an incandescent bulb is the functional unit of the bulb. As an electric current passes through, the filament heats up and emits light as the intensity of the heat increases. Originating from the minerals wolframite and scheelite, tungsten is mined predominantly through underground mines, located throughout the world (Madehow, 2009). The cost of purifying and process for tungsten are relatively low as the ore is often processed and extracted onsite by means of crushing and froth floatation. The element has no adverse affects on the environment and the reuse of tungsten through recycling from other products is possible (International Tungsten Industry Association, 2002).

The base of the light bulb is made out of a mixture of brass and aluminum, two readily available metals found in open pit and underground mines across the world.

The final addition to the bulb is a nitrogen and argon gas mixture. The air within the bulb is vacuumed out and the gas mixture is injected to prolong the life of the filament. These gases are naturally occurring and freely available in the atmosphere.

It should also be noted that large manufactures such as Koninklijke Philips Electronics, have been making incandescent light bulbs in the United States, Hong Kong, Mexico and India since the end of the Second World War (Koninklijke Philips Electronics, 2009). The materials and production costs of incandescent light bulbs are low due the streamlined production process and the availability of cheap raw materials. The materials in the bulb and base can be recycled at the end of the bulb's lifetime and used in new products. The tungsten, however, is evaporated into the atmosphere over the lifetime of the bulb.

## 2.2 Compact Fluorescent Lamps (CFL)

The CFL bulb, seen in Figure 2, has a similar base and bulb structure to the incandescent light bulb, and thus has similar environmental impact and sustainability issues. The main difference between CFL and incandescent bulbs is that the CFL does not rely on a filament to emit light; rather, a current is passed through a glass chamber filled with mercury vapor (Energy4You, 2008). This emits an ultraviolet light that excites a phosphor coating on the inside of the tube that emits visible light. The use of mercury and phosphor in CFL bulbs greatly increases the negative impacts on the environment and causes the continued use of CFL bulbs to be unsustainable. Extracting mercury involves several processes, all of which are environmentally damaging and unsustainable in the long term; they include open pit mining, inefficient mercury refinement techniques, and the use of sulphur dioxide-emitting natural gas-driven furnaces (Enotes, 2008). Mercury, and especially mercury vapour, is extremely toxic to the environment and its use is heavily regulated. The average CFL bulb contains approximately 4 mg of mercury (BC Hydro, 2009). Although phosphor is not nearly as toxic as mercury, the production and refinement processes are energy intensive and environmentally damaging. CFL’s also contain a number of minor electrical parts, contained in a simple electrical circuit and an outer plastic coating. These parts come from a variety of sources and materials, but are considered trace amounts by composition and by environmental impact when compared to the rest of the bulb.

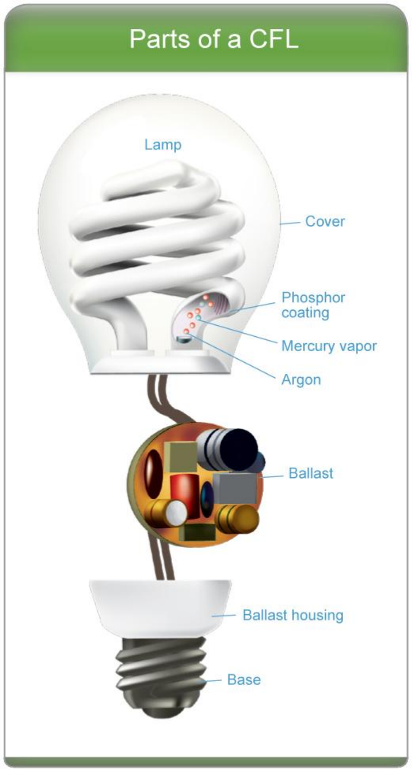


Figure 2: The Compact Fluorescent Bulb
*Source: http://www.energystar.gov*

Due to the relatively high cost of production for CFL’s, the majority of production is in China and Mexico (Lamptech, 2007). The raw materials used in the production of CFL’s are not only unsustainable, but also have adverse effects on the environment. The production process requires that unsustainable materials are combined and used in such a way that reclamation after the usable lifetime is impossible.

Although CFL’s use mercury in their consumer state, mercury is a by-product of coal power, which generates the majority of the world’s energy. Since more energy is required to power an incandescent light bulb than a CFL bulb, incandescent light bulbs can excrete more net mercury into the atmosphere (Figure 3).Due to the recent developments in LED technology, it is uncertain how an LED light bulb compares in the figure.

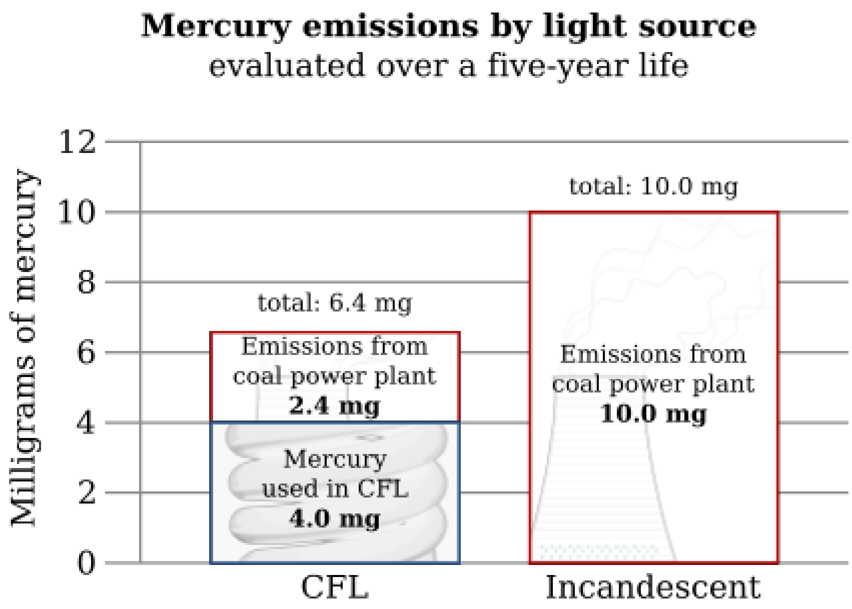


Figure 3: Comparison of Mercury Usage based on Coal Generated Power
*Source: T.A. Burnett, D. L. Dycus, W. J. Parkhurst (2002)*

## 2.3 Light Emitting Diodes (LED)

LED's share the same common components inherent to all light sources examined in this paper: metal leads, outer plastic casing and transparent housing. What separates LED's from the other light sources is that no filament is used; they use electricity passing through silicon wafers to emit light (Madehow, 2009). Silicon wafers are made of almost 100% silicon, which is refined from silicon dioxide, the most abundant compound in the earth's crust. There are many processes to refine silicon dioxide into silicon, all of which are sustainable as long as a sustainable source of energy is used. The second unique component of LED's is the heat sink module, which is typically made of copper or aluminum due to their high thermal conductivities (EarthLED, 2009). As these metals are easily recyclable and reusable, there is no issue with their sustainability. As with most metals, they are extracted through various mining processes in locations all over the world. An exploded view of the LED light bulb can be seen in Figure 4.

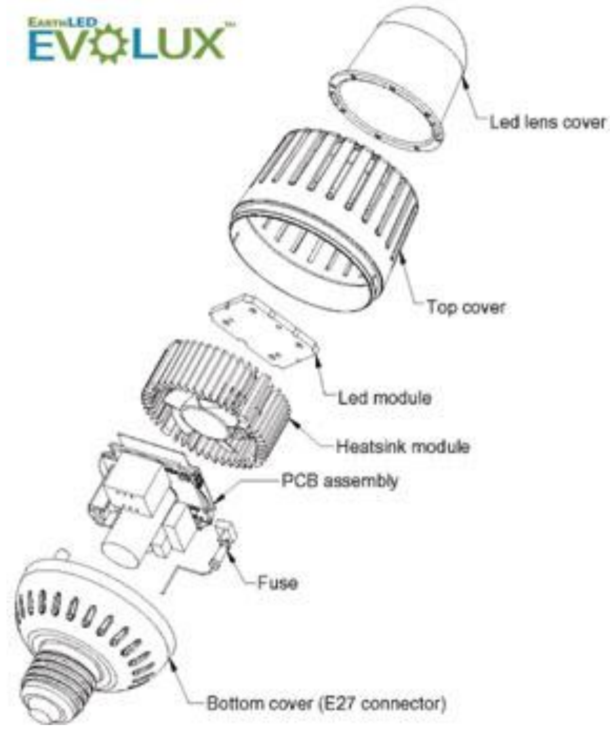


Figure 4: The LED Light Bulb
*Source: http://www.earthled.com*

The productions of LED's are almost exclusively limited to overseas factories in China, Taiwan and Japan, using fully automated processes. EarthLED, one of the leaders in LED light bulb technology, believes that due to this small market share, their Taiwan-made LED light bulbs are anywhere from 10 to 100 times more expensive to manufacture than an equivalent output compact fluorescent (EarthLED, 2009).

## 3.0 THE USAGE OF LIGHT

Every type of light bulb is capable of generating equal amounts of light; however they all differ in the amount of energy they require as well as their lifespan. In the interest of determining the most sustainable option, energy use and lifetime are crucial.

### 3.1 Incandescent

To determine which type of light bulb has the best usage advantage, the cost, the lifetime and the operation/power consumption of each bulb will be considered as the comparative parameters. We first start with the incandescent light bulbs. The term incandescence means "emitting visible light as a result of being heated" (Answers.com, 2009). From the meaning of the name of this type of light bulb, one can see that it will need to produce a large amount of heat in order to provide light. Incandescent light bulbs work "by passing an electric current through a thin filament wire (usually of tungsten) until the wire is extremely hot" (GLOBALSPEC, 2009). So the energy consumed will be the energy used to provide the electric current to heat up the filament inside the bulb. The disadvantage of incandescent light bulbs is that a large portion of the energy is transformed to heat, so a large amount of energy is needed in order to produce a certain amount of light compared to other types of light bulbs such as the CFL and LED light bulbs. The cost of incandescent light bulbs, however, is much less compared to the CFL's and LED's. An incandescent light bulb typically costs around $1 each and they last around 1500 hours, which is a little over 2 months.

### 3.2 Compact Fluorescents

CFL light bulbs consist of "a glass tube filled with a mixture of argon gas and mercury vapour at low pressure. When the current flows through the ionized gas, between the electrodes, it emits ultraviolet radiation from the mercury arc which is converted to visible light by phosphor coating on the inside glass of the tube" (STANDARD, 2009). The energy consumed in a CFL is used to produce an electric current to cause the mercury vapour to emit ultraviolet light, which is much less energy compared to the amount to power an incandescent light bulb. Another advantage of a CFL is that it produces more light energy from a certain amount of electrical energy consumed compared to incandescent and LED light bulbs. A disadvantage of the CFL is that, due to its electronic properties, these light bulbs do not respond well in dimming applications. The cost of a typical CFL light bulb is around $3 each and they last around 10,000 hours, which is a little over 1 year, much longer than incandescent light bulbs.

### 3.3 LEDs

Lastly, LED light bulbs are “semiconductor devices which convert electricity into light” (Toolbase Services, 2009). The energy consumed is the energy needed to operate the semiconductor diode, which is much less compared to both incandescent and CFL light bulbs. Large advantages of the LED light bulbs are their long lifetime; they can last for years without requiring replacement, while consuming very little energy. One disadvantage of the LED light bulbs is the amount of light produced from a certain amount of energy. Most LED light bulbs on the market provide “2.5 times less light than CFL’s” (MapAWatt, 2009). With rapid advances in technology, LED bulbs are becoming more efficient and providing light comparable to a typical 60W incandescent, but with higher light output comes higher temperatures which can decrease the life of an LED much more dramatically than other light bulbs (EarthLED, 2009). There has not been a major light bulb manufacture to produce high output LED light bulbs on a large commercial scale, which results in another disadvantage of LED’s: the high cost of the light bulbs. The cost of a typical LED light bulb is around $50 each, but they last around 60,000 hours, or almost 7 years. Cost per bulb is expected to fall dramatically in the next few years as the infrastructure and technology develops (EarthLED, 2009).

### 3.4 Quantitative Comparison

Table 1 gives a quantitative comparison of the three different types of light bulbs. The analysis is based on the hours of usage and the cost of the light bulbs. Over an illuminated time of 60,000 hours (around 9.5 years of usage with 17 hours of operation per day), the cost for the operating and purchasing 100 incandescent light bulbs is $41,380.00, for 100 CFL’s is $10,188.00, and for 150 LED’s is $13,642.50. 150 LED light bulbs would be required to obtain the equivalent light output as 100 CFL’s using the average LED light bulb available. The CFL is the most economical in regards to operating cost, with LED’s costing around 1.3 times more and incandescent light bulbs costing upwards of 4 times more than the CFL’s.

However, analyzing solely the energy consumption for each light bulb, LED light bulbs are the most efficient costing $558.45 per year to operate or $36 per bulb. The CFL's are second at $868.70 per year to operate or $87 per bulb. Finally, the incandescent bulbs cost $3,723.00 per year for energy alone, meaning over $370 per bulb. This shows that the incandescent light bulbs will consume a significant amount more energy than the CFL and LED light bulbs.

Table 1: Energy Savings Calculator for Replacing Light Bulbs
*Source: Robert O'Neill, 2006*

**Energy Savings Calculator for Replacing Light Bulbs**

| | Incandescent Light Bulbs | CFL | LED |
|---|---|---|---|
| Life Span (in hours) | 1,500 | 10,000 | 60,000 |
| Watts | 60 | 14 | 6 |
| Cost | $1.345 | $2.98 | $54.95 |
| KWh of electricity used over 60k hours | 3,600 | 840 | 360 |
| Electricity Cost (@ $0.10 per KWh) | $360.00 | $84.00 | $36.00 |
| Bulbs needed for 60k hours of usage | 40 | 6 | 1 |
| Equivalent 60k hour bulb expense | $53.80 | $17.88 | $54.95 |
| **Total 60,000 Hour Lighting Spend** | **$413.80** | **$101.88** | **$90.95** |
| **Calculate Your Energy Savings** | | | |
| # of household light bulbs | 100 | 100 | 150 |
| Your estimated daily usage (hours) | 17 | 17 | 17 |
| Days in month | 30 | 30 | 30 |
| *Household savings over 60,000 hours (energy + replacement)* | | | |
| Household cost | $41,380.00 | $10,188.00 | $13,642.50 |
| Savings by switching from Incandescent | $0.00 | $31,192.00 | $27,737.50 |
| *Monthly household energy savings* | | | |
| KWh used per month | 3,060 | 714 | 459 |
| Electricity Cost (@ $0.10 per KWh) | $306.00 | $71.40 | $45.90 |
| Savings by switching from Incandescent | $0.00 | $234.60 | $260.10 |
| *Yearly household energy savings* | | | |
| KWh used per year | 37,230 | 8,687 | 5,585 |
| Electricity Cost (@ $0.10 per KWh) | $3,723.00 | $868.70 | $558.45 |
| Savings by switching from Incandescent | $0.00 | $2,854.30 | $3,164.55 |

Another light bulb usage calculator was used and the results are shown in Table 2. The total cost for lighting based on a 60,000 hour lighting time is shown and is very similar to the results from the previous analysis. Therefore it is certain that incandescent light bulbs should not be used for the new SUB due to their high energy consumption and short lifetime.

Table 2: Lighting Cost Comparison
*Source: MapAWatt, 2009*

| | | | | | | |
|---|---|---|---|---|---|---|
| Electricity Cost (cent/kWh) | $0.10 | | | | | |
| Light on/Day (hrs) | 17 | | | | | |
| | | | | | | |
| Type | Watts | Lumens | Lumens/ Watt | Price/Bulb | Annual Operating Cost | Life (Hours) |
| **Incandescent** | 60 | 765 | 12.8 | $1.35 | $37.23 | 1500 |
| **CFL** | 14 | 900 | 64.3 | $2.98 | $8.69 | 10000 |
| **LED** | 6 | 336 | 56 | $54.95 | $3.72 | 60000 |

| "Years" | Hours On | | | | | | |
|---|---|---|---|---|---|---|---|
| 9.65 | 59878.25 | Bulbs (round up) | "Years" elec. consumption (kWh) | Elec. Cost | Total Cost (electricity + cost/bulb) | # Light bulbs in Building | Total Cost of Lighting for the Building |
| | Incandescent | 40 | 3592.695 | $359.27 | $413.07 | 100 | $41,306.95 |
| | CFL | 6 | 838.2955 | $83.83 | $101.71 | 100 | $10,170.96 |
| | LED | 1 | 359.2695 | $35.93 | $90.88 | 150 | $13,631.54 |

Although frequent cycles of being turned off and on can decrease a light bulb’s lifespan, the lifetime ratings of bulbs are based on a 3 hour operation time for each time the bulb is turned on. In other words, if the light bulb is turned on and off once every three hours, it should last until the rated lifetime. But for lighting inside the SUB, where the lights will usually be on for more than 3 hours without being switched off, they should all last longer than their rated lifetimes (lighting design lab, 2009). The efficiencies of each light bulb are based on the lumens per watt value shown in Table 2. The higher the value, the more light is produced from a certain amount of wattage, which means the bulb is more efficient.

## 4.0 RECYCLING AND DISPOSAL OF LIGHT BULBS

All light bulbs will deteriorate and die over time. An important factor to consider when determining the sustainability of each type of bulb is how the bulb is to be recycled or disposed of at the end of its life. Different materials can cause toxic or harmful effects if not dealt with properly, while other materials are often not reused and simply thrown out.

### 4.1 Incandescent Light bulbs

The incandescent light bulb has been used throughout the world since the mid 1800's. The technology has gone unchanged, and unfortunately, so has the disposal of the bulbs. Since the realization that the planet is a finite system, recycling of incandescent bulbs has begun, but on a very minimal scale for the incandescent bulbs. "They aren't high on the priority list, because they don't contain toxic materials and don't offer much in the way of recoverable resources" (Gilchrist, 2008). For the most part, recycling systems of incandescent light bulbs have not been set up in Canada or the United States.
As mentioned in section 2.1 of this report, many of the components of an incandescent light bulb are relatively inexpensive to produce. The only component that is currently being recycled is the glass. It can be easily melted down to form new glass products. This comes with an additional cost as it is expensive and an economically unviable process to dismantle individual incandescent light bulbs (Gilchrist, 2008). The materials are often more economically reproduced than recycled, leading most incandescent light bulbs to the local landfill. Currently, Metro Vancouver's waste is being transferred to the Delta landfill, which has been in operation since 1966. The landfill is currently the only large landfill in the area and is expected to close within in next decade (Henderson, 2004).

It was announced in 2007 that the Canadian Federal Government would "ban the sale of inefficient light bulbs by 2012 in a move to reduce energy consumption and reduce greenhouse gases" (CBC News, 2007). This ban has already been implemented elsewhere in the world. As of September 1$^{st}$ 2009, all countries in the European Union can "no longer be [buying] or import most incandescent frosted glass bulbs." The United States will phase the incandescent light bulb out of the market by 2014.

## 4.2 Compact Fluorescent Light Bulbs

It is a well publicized fact that compact fluorescent light bulbs contain mercury. This element is an essential part of the bulb and cannot simply be substituted. This poses the greatest concern when disposing of the light bulbs. Since every bulb contains on average 3-4mg of mercury, with increasing number of light bulbs ending up in a landfill, more mercury is projected to enter our environment through groundwater leeching and eolian means. “The U.S. Environmental Protection Agency estimates that in 2007, 270 million CFL bulbs were sent to landfill sites instead of recycling them” (Wikipedia, 2009). This equates to 1.08 metric tonnes of mercury in 2007 for the United States alone. Mercury is a highly toxic element. “Exposure to elemental mercury can result in effects on the nervous system, including tremor, memory loss and headaches. Other symptoms include bronchitis, weight loss, fatigue, gastro-intestinal problems, gingivitis, excitability, thyroid enlargement, unstable pulse, and toxicity to the kidneys” (Environment Canada, 2004). In the United States, the Resource Conservation and Recovery Act (RCRA) and in Canada, the Canadian Environmental Protection Act, have been established and constantly updated to deal with the transport, treatment, storage, and disposal of hazardous waste (Environment Canada, 2004). Protection from exposure is increasing the demand for recycling facilities specifically for compact fluorescent light bulbs.

One advantage the compact fluorescent light bulb has over its incandescent siblings is that most of its components of can be recycled. To extract the mercury from the bulb, recycling plants “utilizes a small vacuum chamber that is constantly rinsed with water. The lamps are fed into the machine and once in the vacuum chamber, the end of the lamp is broken open. The vacuum draws out the mercury and phosphorus and cold water is used to keep mercury in its most transportable state, a liquid” (BC Hydro, 2009). The remaining components from the ballast are sent back to the manufacture to be reused or regenerated into new components and the glass is melted down to create new glass products (Aucott, McLinden, & Winka, 2003). Currently, large companies such as IKEA and Home Depot accept CFL bulbs all around Canada and deliver them to appropriate recycling plants at no cost (BC Hydro, 2009). To attract more users to switch from incandescent to compact fluorescent bulbs, all CFL bulbs qualified by ENERGY STAR are backed by a two year warrantee.

### 4.3 Light Emitting Diode Bulbs

Due to the recent advances in LED technology, recycling is not yet an option. The infrastructure does not exist like it does for CFL's (EarthLED, 2009). Due to the predicted long life of an LED light bulb, even if disposed of improperly in the garbage, 40 incandescent light bulbs would end up in the landfill for every single LED bulb. However, this is not an adequate solution. It is predicted that LED lights will be simply shipped back to the manufacturer, where parts can be reused or recycled (EarthLED, 2009). Currently, all LED light bulbs are being disposed of with other electronic goods, so depending on the location, this could mean a small recycling plant or in most cases, the landfill.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

By evaluating each lighting option using a triple bottom line comparison we were able to examine the complete life cycle in order to find the optimal choice for the new Student Union Building. We evaluated the materials, production process, usage and disposal of each light bulb. Although our data and research indicates that LED's present the most sustainable choice in terms of materials and usage, we are unable to fully recommend this option at the current time. As LED's are a relatively new technology, their production process is relatively inefficient; hence they take more energy to produce. Also, even though LED's are made from 100% recyclable materials, programs have not yet been put in place to do so. That being said, if current trends continue, these issues will be resolved by the time the new SUB will begin construction. If this is indeed the case, this report has come to the conclusion that LED's is the best choice for the new SUB, when keeping UBC's design goals in mind.

However, if this is not the case, CFL's provide have proven a more than adequate sustainable alternative, providing that the used bulbs are recycled the proper manner, as discussed within this report.

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